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Performance Summary for the First Solar CdTe 1-kW System

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ABSTRACT

This paper describes the performance of a 1-kW$_{ac}$ CdTe PV array from First Solar (formerly Solar Cells, Inc.) operated at NREL from June 1995 to November 2000. The PV array operating efficiencies over the 5.5-year period were calculated from 15-minute averages to determine changes in seasonal and annual performance. Performance measurements of each module were also made before installing the modules outdoors and again in August 2000 using NREL's indoor SPIRE 240A pulsed solar simulator and the Standard Outdoor Measurement System (SOMS). Although some modules showed increases in efficiency and others decreases, the average efficiency of the modules in the PV array did not change. For modules that showed changes in efficiency, analysis of module I-V parameters indicated that the changes in efficiency were primarily a consequence of changes in fill factor.

1. Introduction

In June 1995, a 1-kW$_{ac}$ CdTe PV array [1] was installed at NREL's Outdoor Test Facility to determine its system operational characteristics over a period of several years with regard to reliability and operating efficiencies. The PV array consists of 24 PV modules from First Solar, faces south with a tilt angle of 30° from horizontal, and is connected to the utility grid through a 2-kW Omnion Series 2200 inverter in a bipolar configuration.

In-situ data for the system were recorded as 15-minute averages using a Campbell Scientific data acquisition system (DAS). The 15-minute averages were used to calculate PV array operating efficiencies over the 5.5-year period (June 1995 to November 2000). Performance measurements of each module were also made before installing the modules outdoors and again in August 2000 using both the indoor SPIRE 240A pulsed solar simulator and the Standard Outdoor Measurement System (SOMS).

2. PV Array Efficiency

Figure 1 shows PV array efficiency as a function of time. Efficiencies were calculated from the DAS 15-minute data and restricted to plane-of-array irradiance values, measured with an Eppley pyranometer, from 950-1050 W/m^2, except during the months of November through January, when the irradiance was restricted to values from 850-1050 W/m^2. Data were corrected to account for sensor drift and calibration. Figure 1 shows seasonal changes due to temperature and spectrum and a small year-to-year decrease in efficiency. Based on a linear least-squares fit, the performance of the array decreased at a rate of 0.7% per year over the 5.5-year period. If only the first four years of operation are examined (to eliminate the fall of 1999, which was abnormally dusty, and the year 2000, when inverter problems occurred), the performance of the array decreased at a rate of 0.6% per year. If projected over the 5.5-year period, this rate would yield a loss in performance of 3.3%.

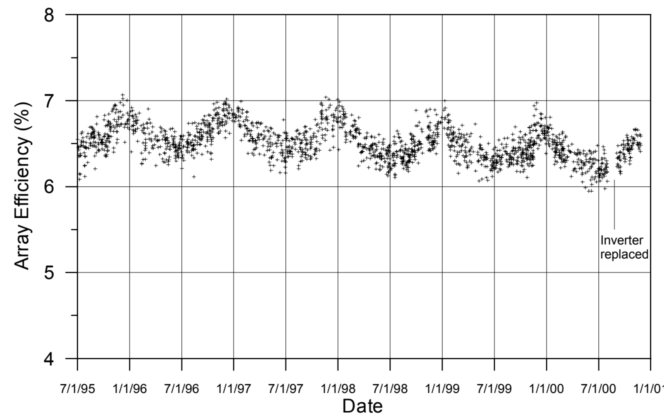

Fig 1. Array efficiency from DAS 15-minute averages as a function of time.

3. Individual PV Module Analysis

Figure 2 portrays a summary of performance changes between baseline and end-of-test (EOT) values in bar-graph format, plotted along the vertical axis for each module. These changes were derived using average efficiency values from multiple I-V points where possible, computed as η_{EOT}/η_{Base} −1. SPIRE and SOMS measurements are depicted. The modules on the left of the graph improved with time and those on the right degraded with time[a]. Because SPIRE and SOMS measurements have different errors (both systematic and random), their results do not compare exactly. However, the differences (8% or less) in results are within the range of values expected for the ±5% error uncertainty of the measurements. For example, for module no. 14708, the SOMS efficiency exhibits little change (-0.7%), but the SPIRE data shows a 6.5% decrease.

Analysis of module I-V parameters reveals that most of the changes in performance can be traced to FF changes. Figure 3 portrays this clearly from SPIRE and SOMS data, a bar-graph plot of relative changes in FF plotted for each module. Comparing Figures 2 and 3, it appears that in some cases—data toward middle and right of the graph—the relative FF changes were actually larger than those in the

[a] The module with the largest decrease in efficiency was no. 12504, a prior-technology module used to replace a module broken during handling. By not including this module, the SPIRE-measured increase in efficiency for the group would be 3% as compared to 2%.

efficiency. Removing modules toward the middle of the graph from consideration—where overall changes in efficiency are minimal—results in both variance and similarity between SPIRE and SOMS data. For data where relative changes to the efficiency are ±4% or more, FF changes generally accounted for over 80% of the relative changes, followed by changes in Voc accounting for 20–30% of those changes. For modules whose performance degraded the most—toward the right in Figures 2 and 3—changes in FF range between 50% and 150% of the efficiency changes for both data sets (SPIRE and SOMS). In cases where the relative FF losses are larger than the entire efficiency losses, there must be opposing increases in either or both Voc and Isc. But there is no systematic trend in these cases—sometimes the Voc change has the same sign as the FF change, at times the opposite sign. Hence, for all the agreement between SOMS and SPIRE data shown in Figure 2, there may yet be some measurement issues. These could be in part associated with pathological problems in performing I-V measurements in some CdTe and other thin-film PV devices—such as capacitance or transient effects.

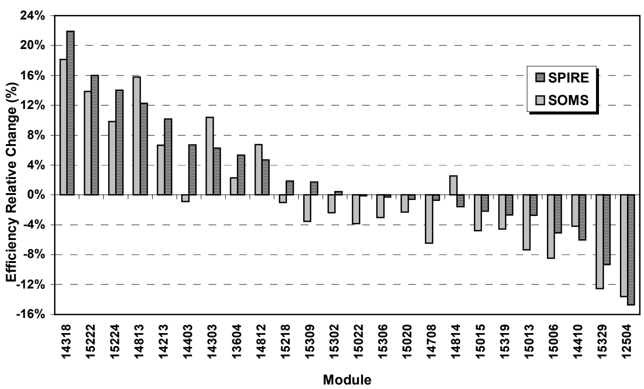

Fig 2. Relative efficiency changes measured using SPIRE and SOMS plotted against module serial number.

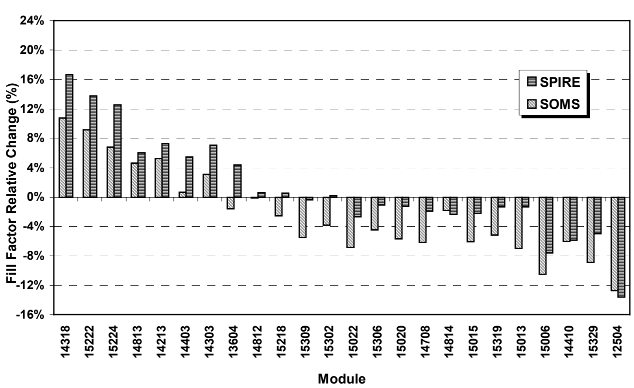

Fig 3. Relative FF changes measured using SPIRE and SOMS plotted against module serial number.

Figure 4 illustrates each module's efficiency at baseline and end-of-test (EOT). The data in this figure represent the average efficiency formed from SPIRE and SOMS measurements at the two junctures. In some cases, there were multiple SPIRE and/or SOMS measurements at baseline and/or EOT. The average values depicted represent the average of SPIRE measurements that were then averaged with the average of the SOMS measurements. Figure 4 shows that some modules improved while others degraded over the 5.5 years of exposure. There is little obvious trend as to which modules improved and which degraded. For example, it is not always the case that the modules that started with lower than average efficiency improved, or vice versa.

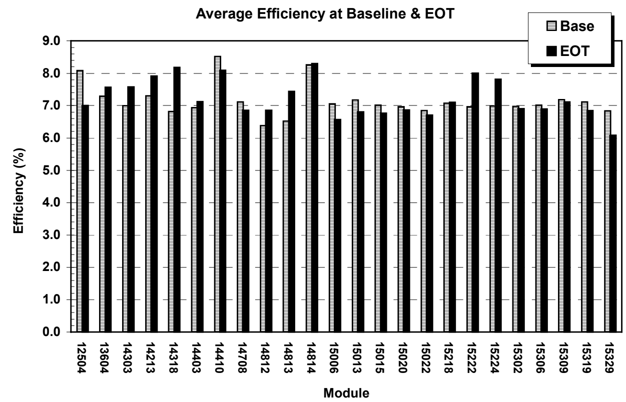

Fig 4. Baseline and end-of-test efficiencies computed as the average of SPIRE and SOMS data.

4. Summary

Reliability of the 1-kW_{ac} CdTe PV array from First Solar was excellent. None of the modules failed during the test period (the only module replaced was broken during handling). PV array efficiencies calculated using over eight thousand 15-minute averages indicated a loss in performance of 0.6% per year, or 3.3% for the 5.5-year test period. This level of stability compares favorably with crystalline silicon modules that degrade at slow, but measurable rates of less than 1% per year [2].

As a group, the average efficiency of the modules over the test period increased by 2% and 0.3% based, respectively, on SPIRE and SOMS measurements. Individual module efficiency changes ranged from –14.7% to +21.9% based on SPIRE measurements and from –13.6% to +23.0% based on SOMS measurements. The absolute accuracy of SPIRE and SOMS efficiency measurements is estimated at ±5%.

5. Acknowledgements

NREL staff Steve Rummel and Allan Anderberg performed the SPIRE and SOMS measurements that were essential for the completion of this work.

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